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Emissions Performance of Alternative Fuel Vehicles: Observations from the Federal Alternative Motor Fuels Programs

Kenneth J. Kelly, **Timothy C. Coburn**,
Robert M. Motta, and Brent K. Bailey



National Renewable Energy Laboratory
Golden, CO

National Renewable Energy Laboratory (NREL)

Center for Transportation Technologies and Systems

Sponsored by the U.S. Department of Energy
Office of Transportation Technologies



Situation

- The U.S. Department of Energy (DOE) is heavily promoting development and deployment of alternative fuels and alternative fuel vehicles (AFVs) to
 - Improve air quality
 - Reduce dependence on imported oil
- On behalf of DOE, the National Renewable Energy Lab (NREL) has undertaken an extensive evaluation of AFVs, including emissions performance
- This presentation discusses
 - Summary results and observations
 - From Round 1
 - Of a multi-round testing program

Background— Federal Alternative Motor Fuels Program

- Originated under
 - Alternative Motor Fuel Act (AMFA) of 1988
- Reinforced by
 - Clean Air Act Amendments of 1990
 - Executive Order 12844
 - Energy Policy Act (EPACT) of 1992
- Requirements (EPACT)
 - New vehicle acquisitions by federal agencies must include an increasing percentage of AFVs, up to 75% in 1999
 - Rules for fuel providers and state government fleets recently implemented

NREL Responsibilities— Federal Alternative Motor Fuels Program

- Develop the data and information resources necessary for consumers, industry, local governments, and DOE to make rational decisions about the use and viability of AFVs and alternative transportation fuels
- Design and implement testing programs that meet or exceed industry standards, and that assure statistically reliable and representative data
- Focus on in-use emissions as opposed to certification data
- Provide timely and succinct analyses and reports of findings
- Track new and on-going technology developments
 - Vehicles/engines
 - Standards
 - Testing procedures
- Establish and maintain objectivity

Objectives— Emissions Testing and Performance Assessment

- Objectively compare the emissions of AFVs **in actual service** to those of otherwise identical vehicles operating on conventional fuels
- Incorporate the latest available technology and vehicle offerings
- Quantify the deterioration of emissions as a result of vehicle age and use, where possible

Test Program Attributes (1)

- Statistically designed study
 - Light-duty
 - Transit buses
- Fleets represented
 - Federal (light-duty, light-duty conversions)
 - Local transit agencies (buses)
 - Private entities and local governments (other heavy-duty)
- Testing facilities
 - Multiple private (light-duty, light-duty conversions)
 - WVU mobile dyno (buses and other heavy-duty)

Test Program Attributes (2)

- Test procedures

- Light-duty

EPA/FTP (exhaust; evap)

Full HC speciation

IM240

- Transit buses

WVU mobile chassis dyno

- Exhaust, CBD driving cycle

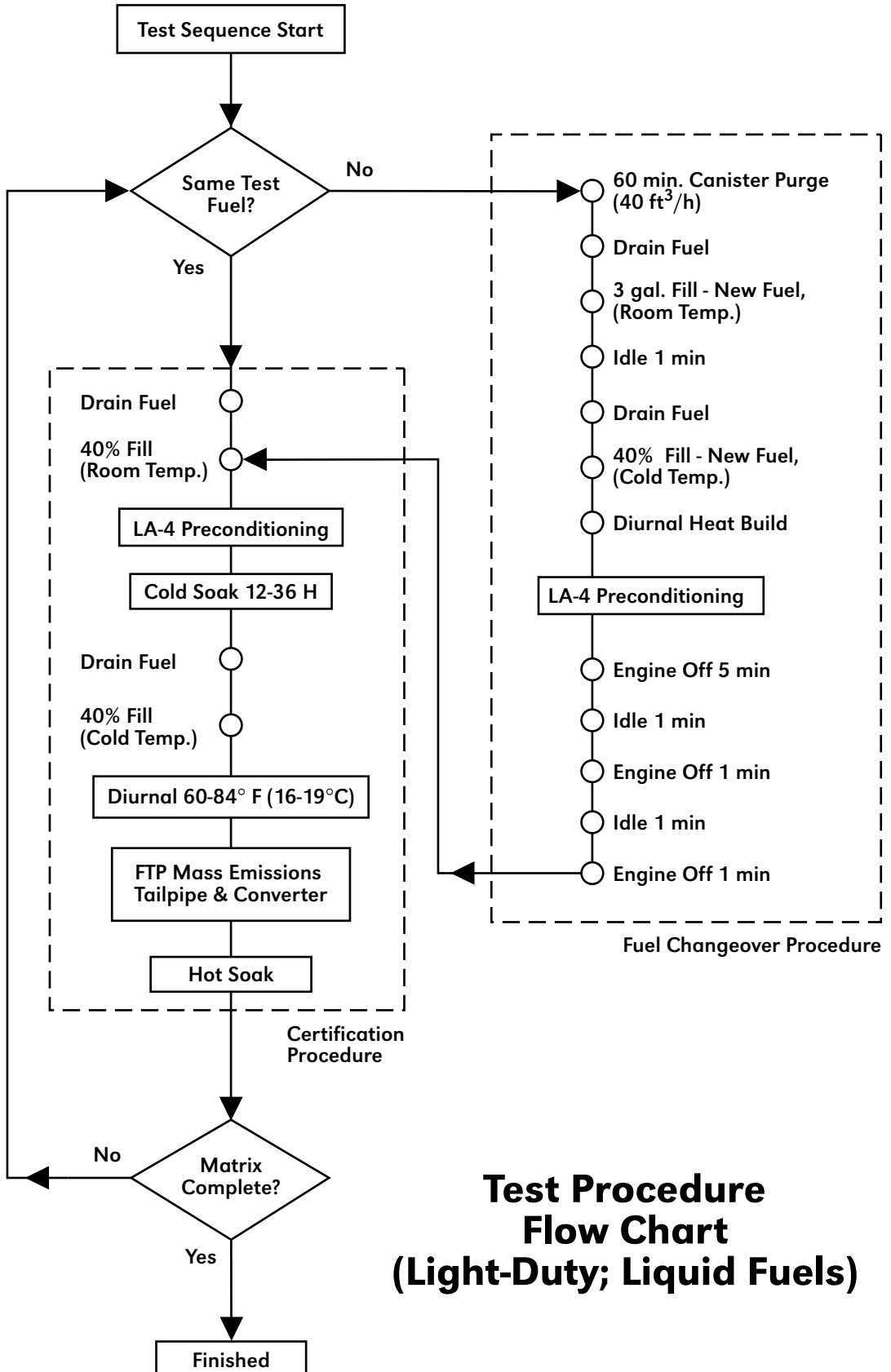
- Other heavy-duty

WVU mobile chassis dyno

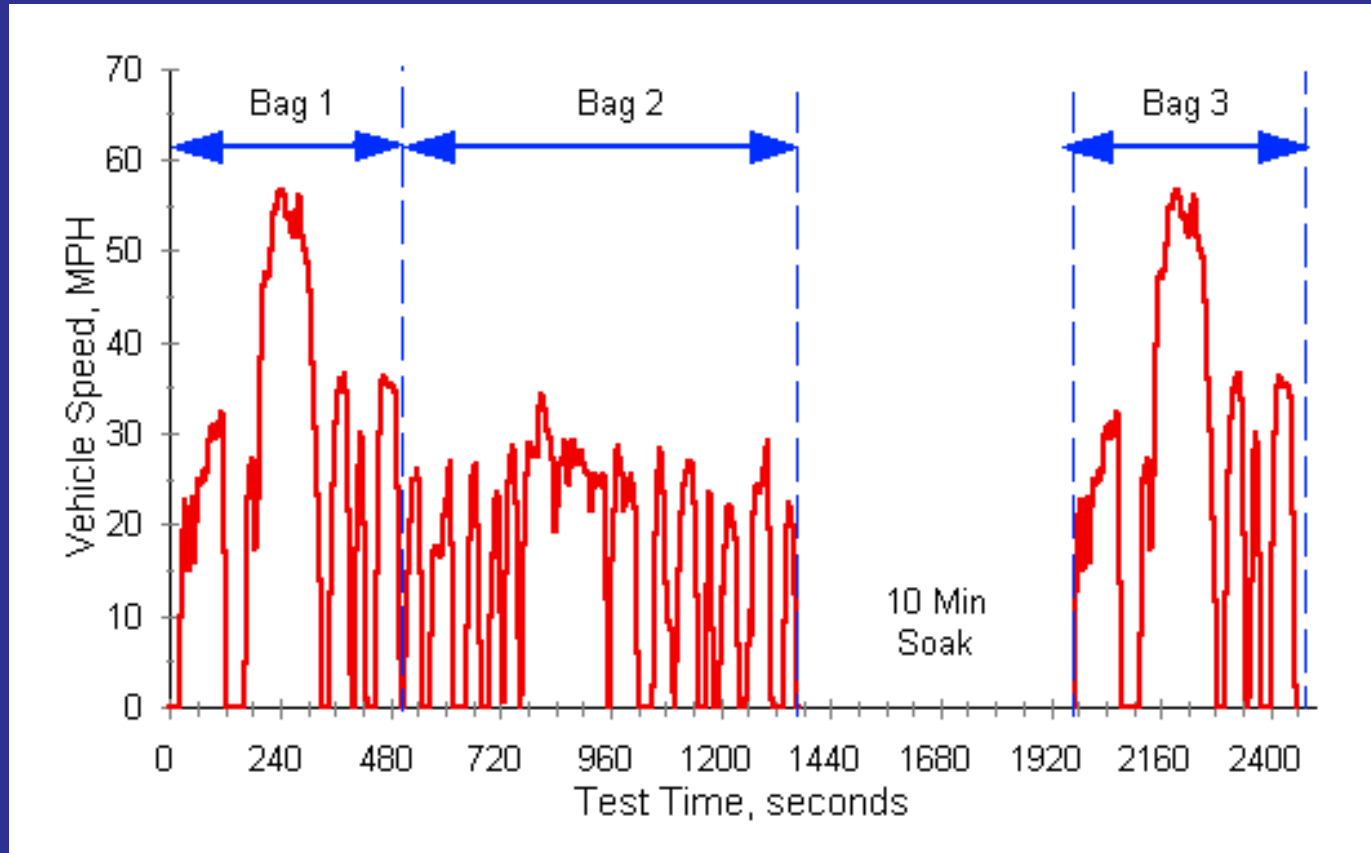
- 5-peak driving cycle for trucks

- Light-duty conversions

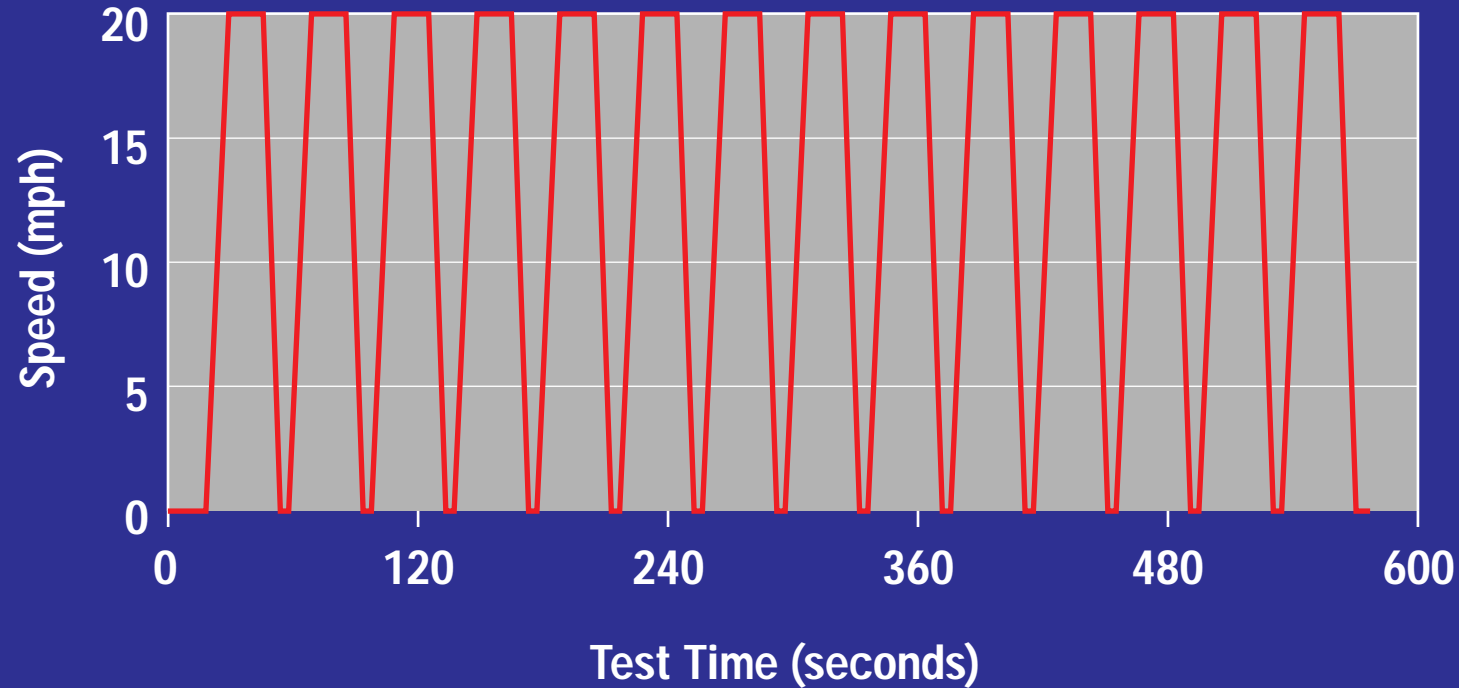
EPA/FTP Bi-fuel (exhaust; evap)



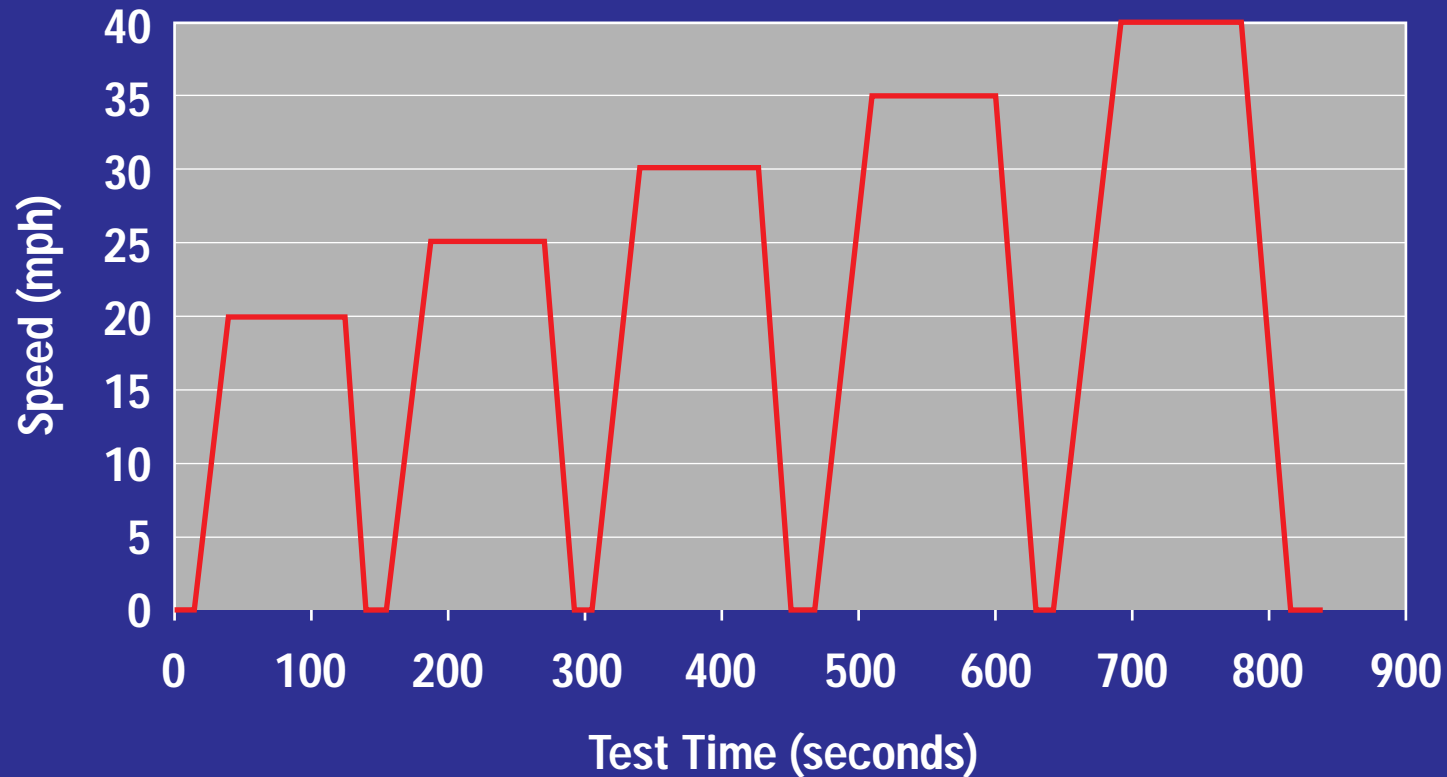
EPA Urban Dynamometer Driving Schedule



Bus CBD Emissions Testing Profile



WVU Truck Emissions Testing Profile



Test Program Attributes (3)

- In-use emissions
- Tests repeated at various mileage levels
- Limited replication at same mileage level
- Target fuels
 - Ethanol, methanol, CNG, and LPG
 - RFG and diesel comparison
- Most extensive study of its kind

Types and Numbers of Vehicles in the Testing Program (Round 1)

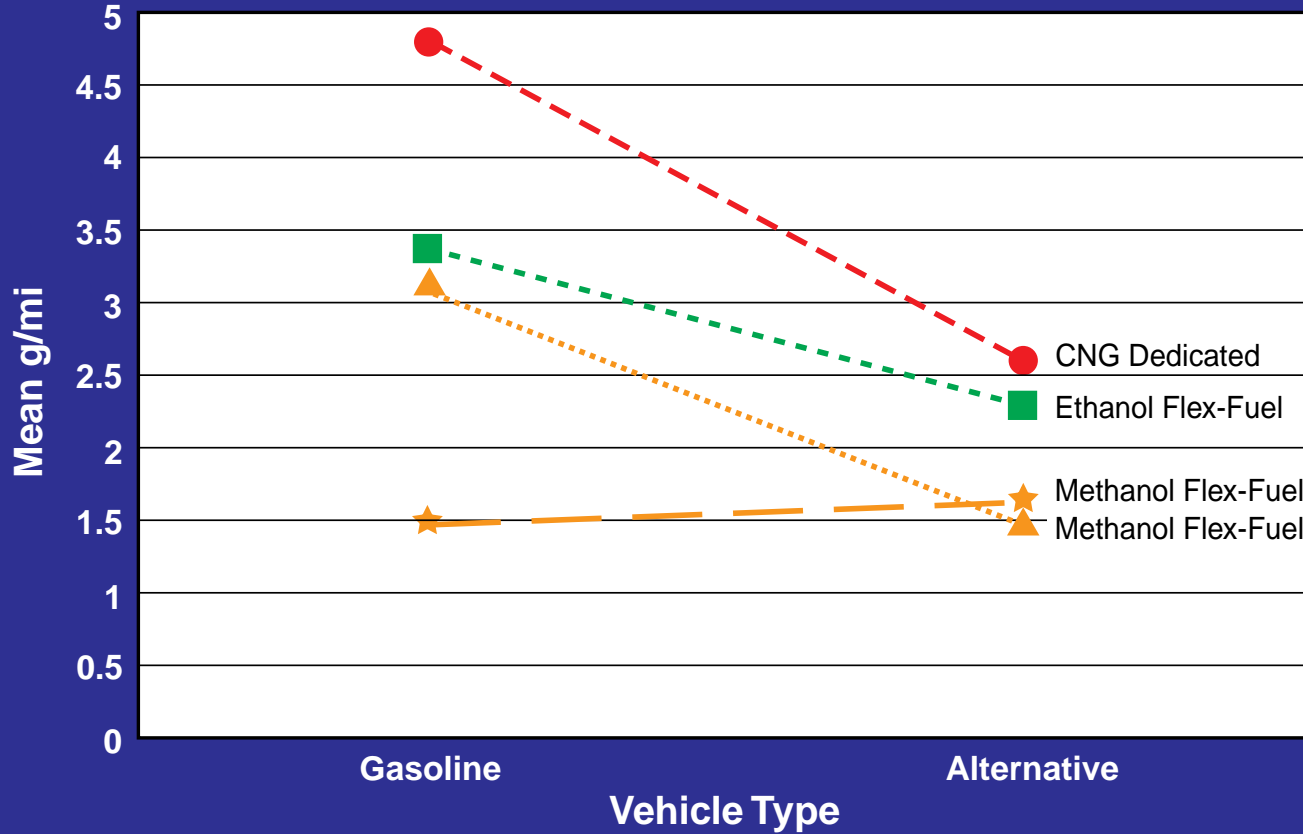
Vehicle Type	Conventional Fuel	Alternative Fuel	Conversions
Light-Duty			
Dodge Spirit Sedans	70	71	•
Chevrolet Lumina Sedans	22	22	•
Ford Econoline Vans	18	16	•
Dodge B250 Vans	38	37	2
Dodge Acclaim Sedans	•	•	2
Chevrolet Astro Vans	•	•	1
Dodge Caravan	•	•	2
GMC Safari Minivan	•	•	2
Ford Taurus Sedan	•	•	3
GMC C1500 Pickup	•	•	2
Ford F150 Pickup	•	•	2
Transit Buses			
Detroit Diesel Engines	17	20	•
Cummins Engines	14	21	•
Other Heavy Vehicles			
Line haul trucks	1	4	•
Snow plows	1	2	•
Garbage packers	3	6	•
Total	184	199	16

Data Availability

Vehicle Type	Emissions Test	Constituents	Scope
Light-duty	FTP exhaust; IM240 exhaust	HC, CO, NO _x Aldehydes Alcohols	All vehicles Alcohol fuel vehicles Alcohol fuel vehicles
	FTP evaporative	HC	Most of vehicles with exhaust tests
	Speciated exhaust	>300 compounds (toxics, O ₃ precursors)	Small % of vehicles with exhaust tests
Transit buses	Chassis dyno exhaust	HC, CO, NO _x , PM	All vehicles
Other heavy-duty	5-peak chassis dyno exhaust	HC, CO, NO _x , PM	All vehicles

Round 1 Test Results: Light-Duty Vehicles

Carbon Monoxide (CO)



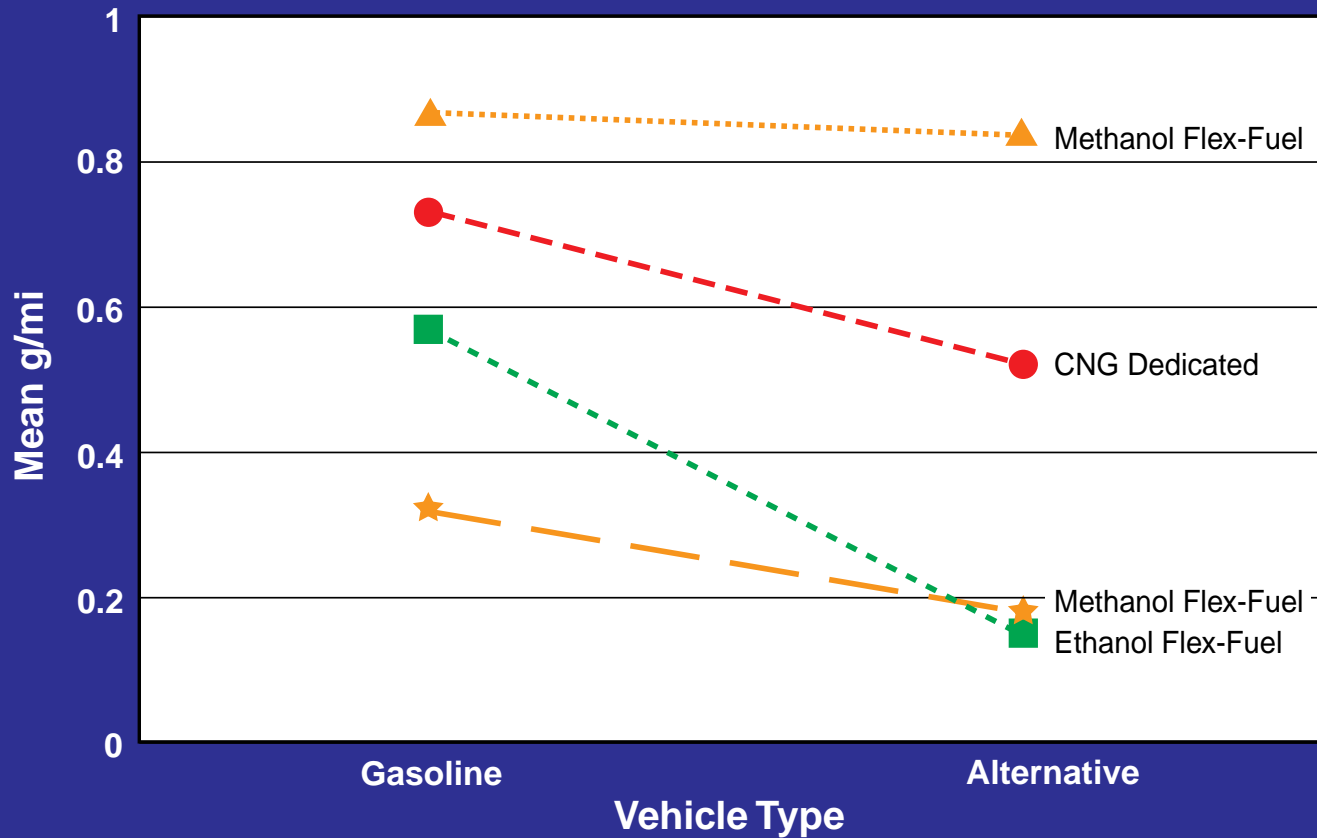
.....▲..... Ford Econoline Vans

-■- Chevy Luminas

—★ Dodge Spirits

-●- Dodge B250 Vans

Oxides of Nitrogen (NO_x)



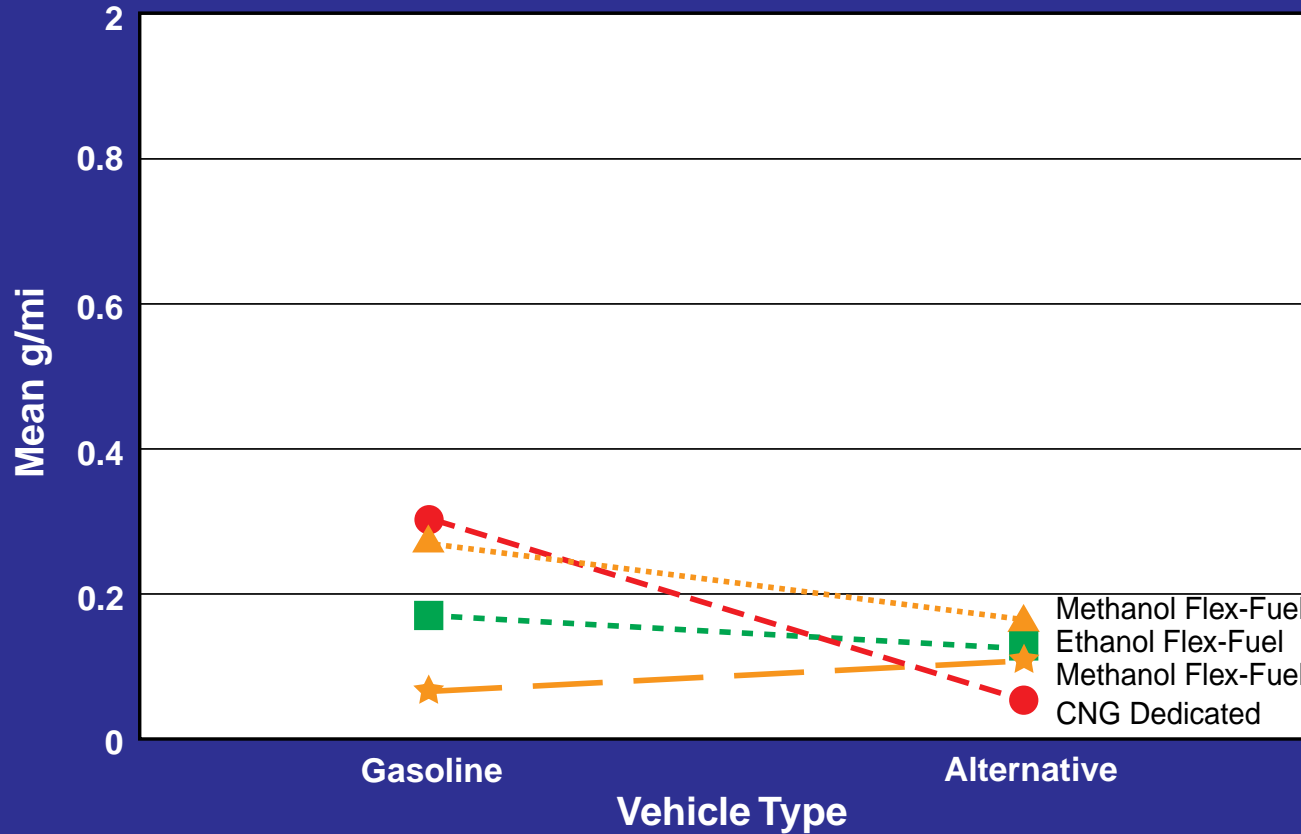
.....▲..... Ford Econoline Vans

- - - ■ - - - Chevy Luminas

———★——— Dodge Spirits

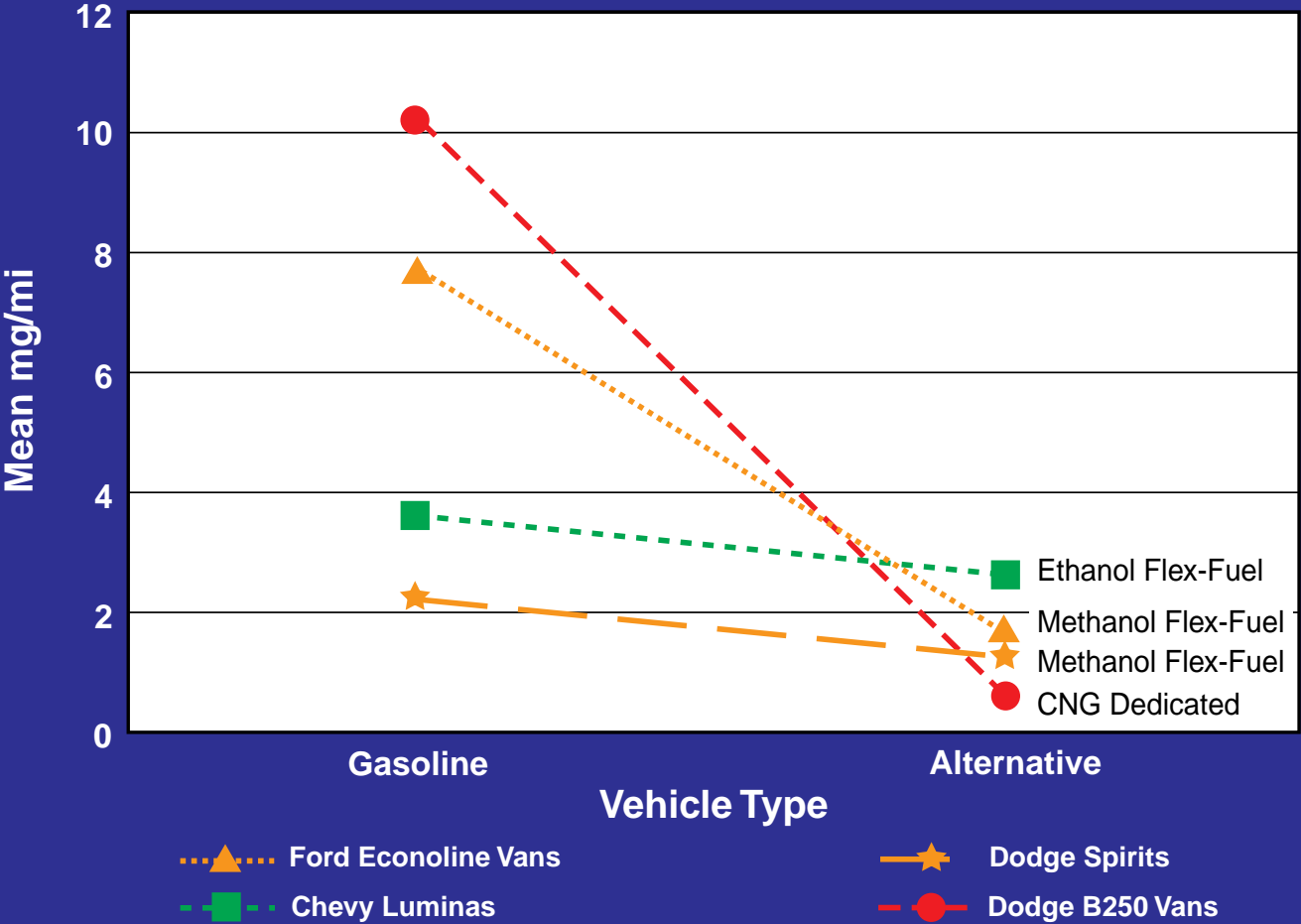
- - - ● - - - Dodge B250 Vans

Hydrocarbons*

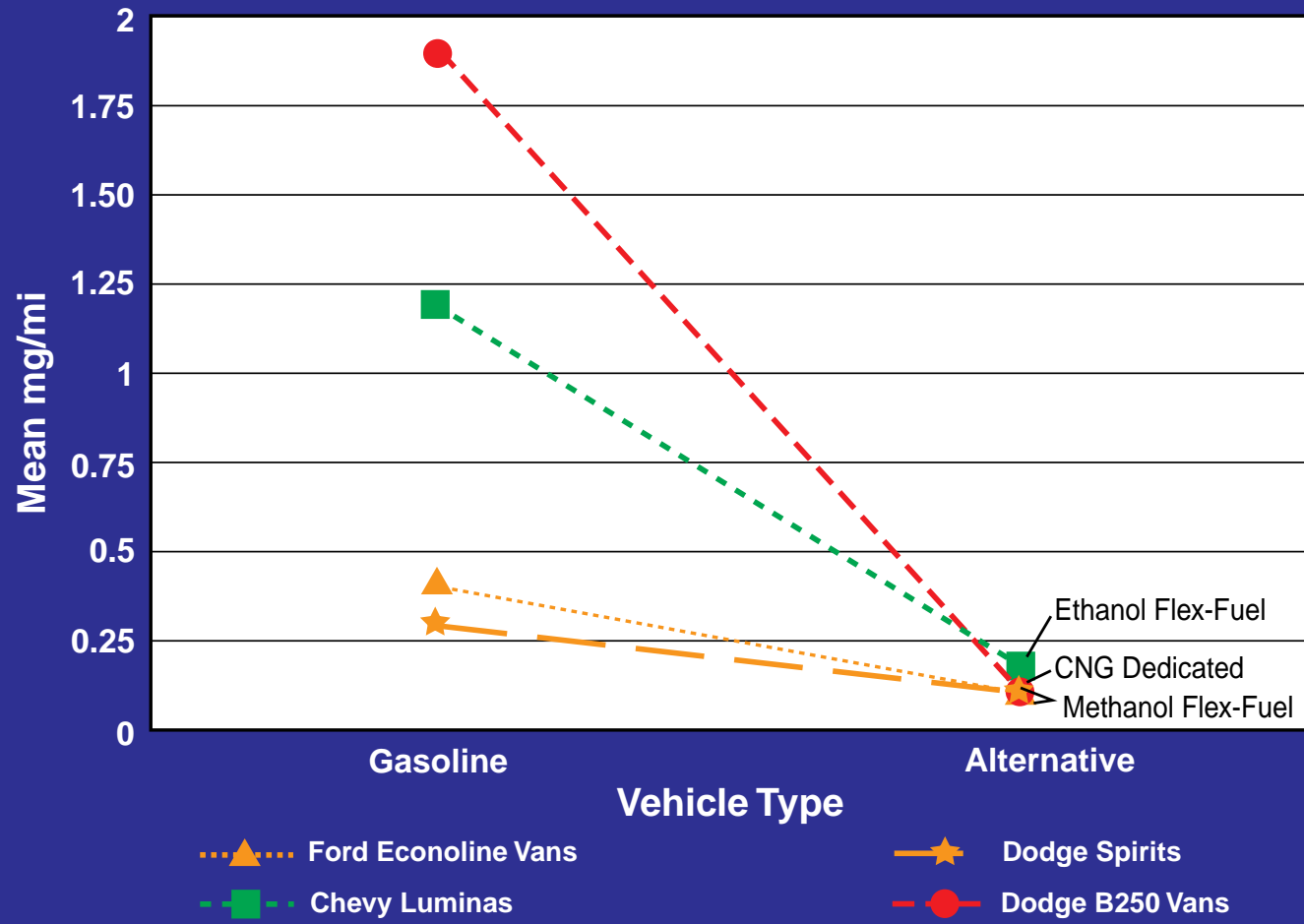


(*CNG = Non-Methane Hydrocarbons; Ethanol & Methonal = Organic Matter Non-Methane Hydrocarbons)

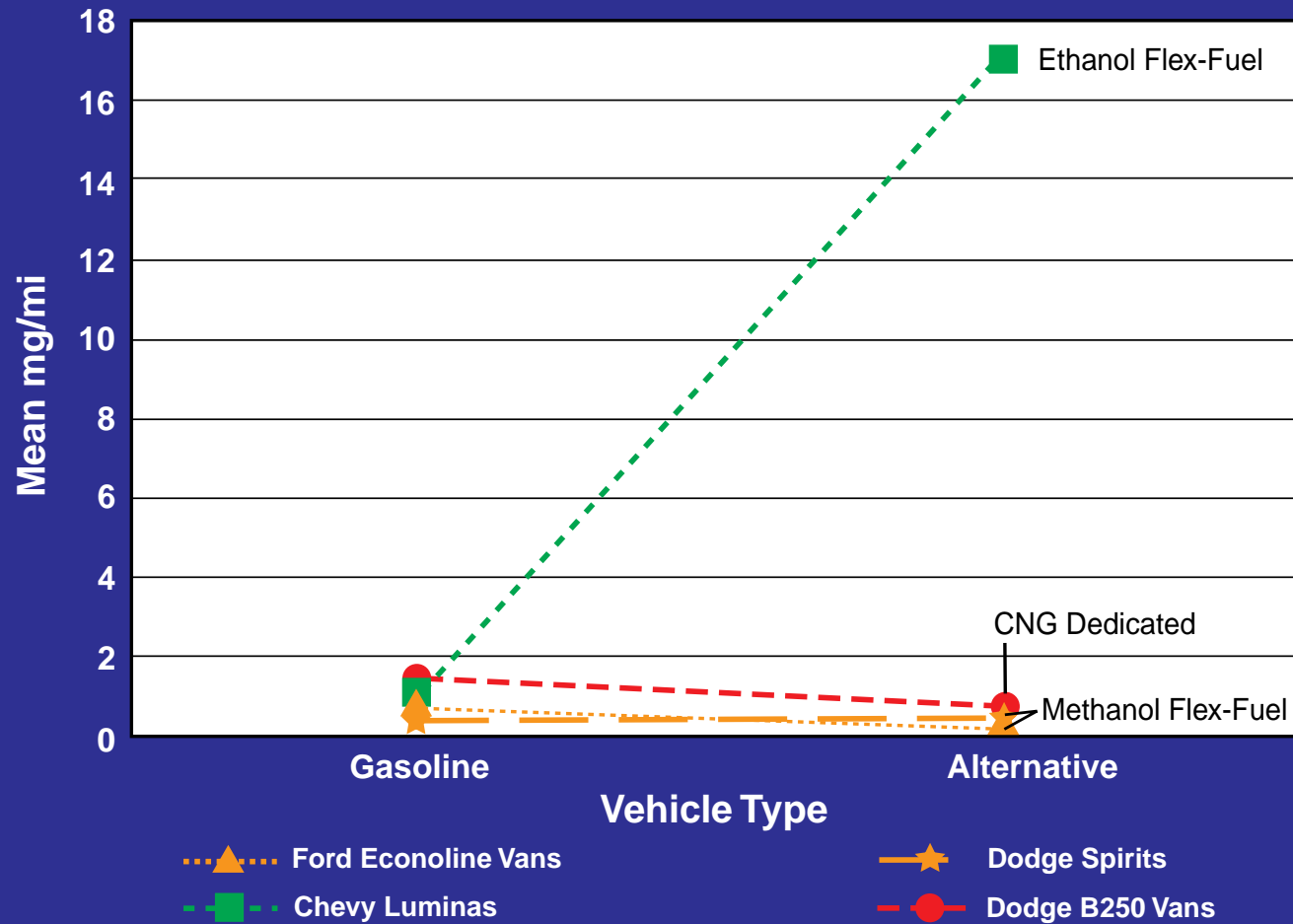
Benzene (C₆H₆)



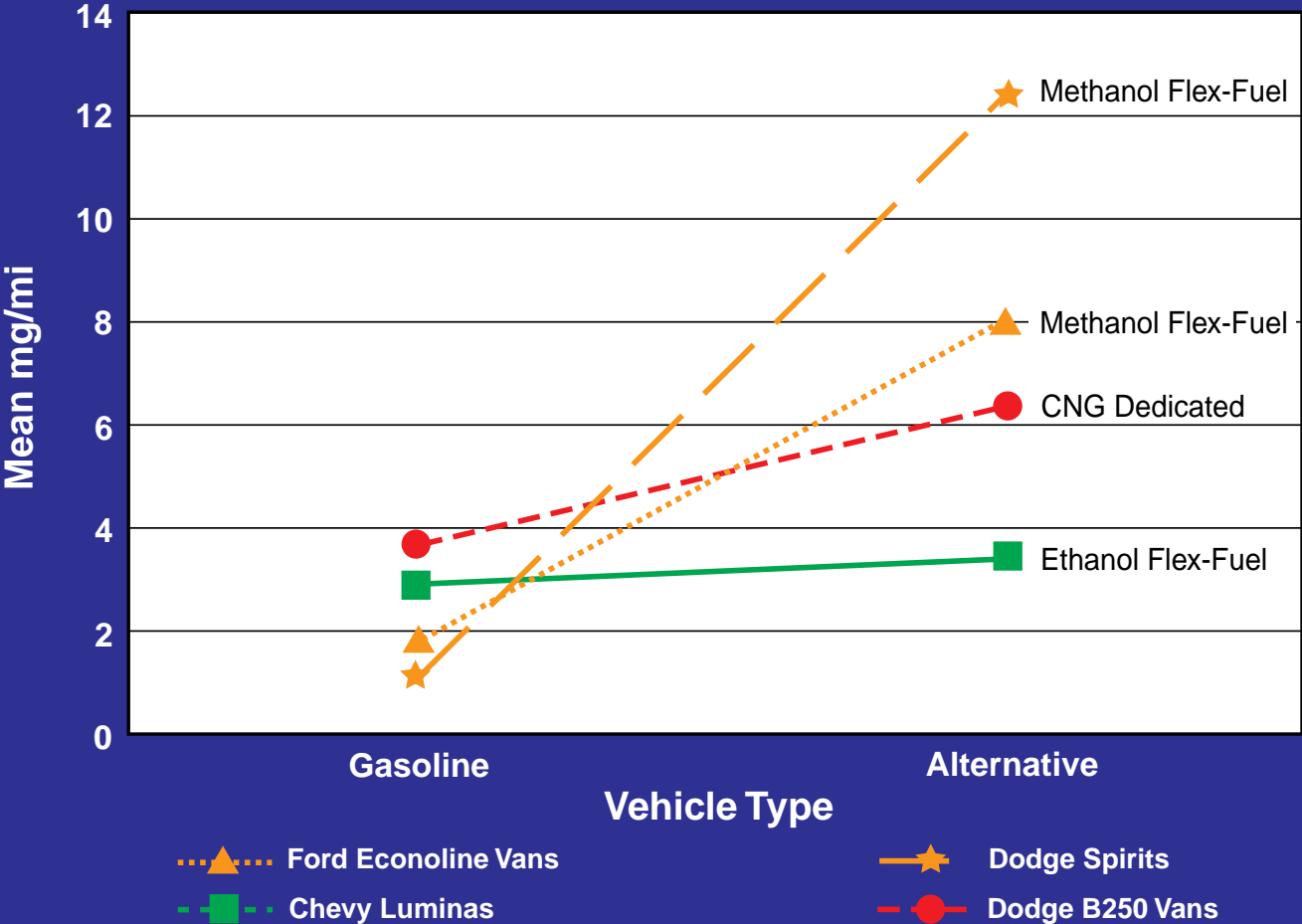
1,3-Butadiene



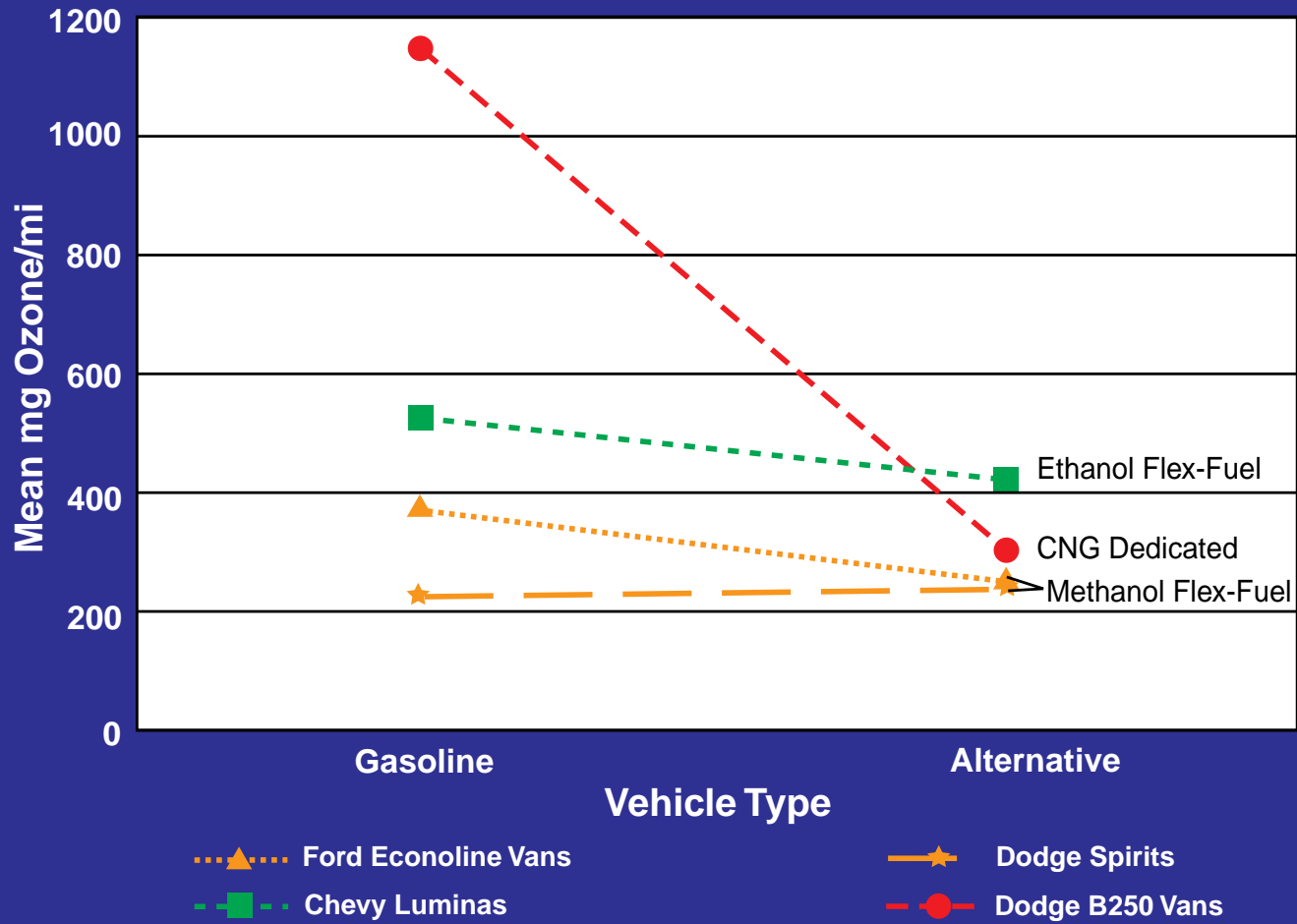
Acetaldehyde (CH_3CHO)



Formaldehyde (HCHO)



Ozone-Forming Potential (OFP)

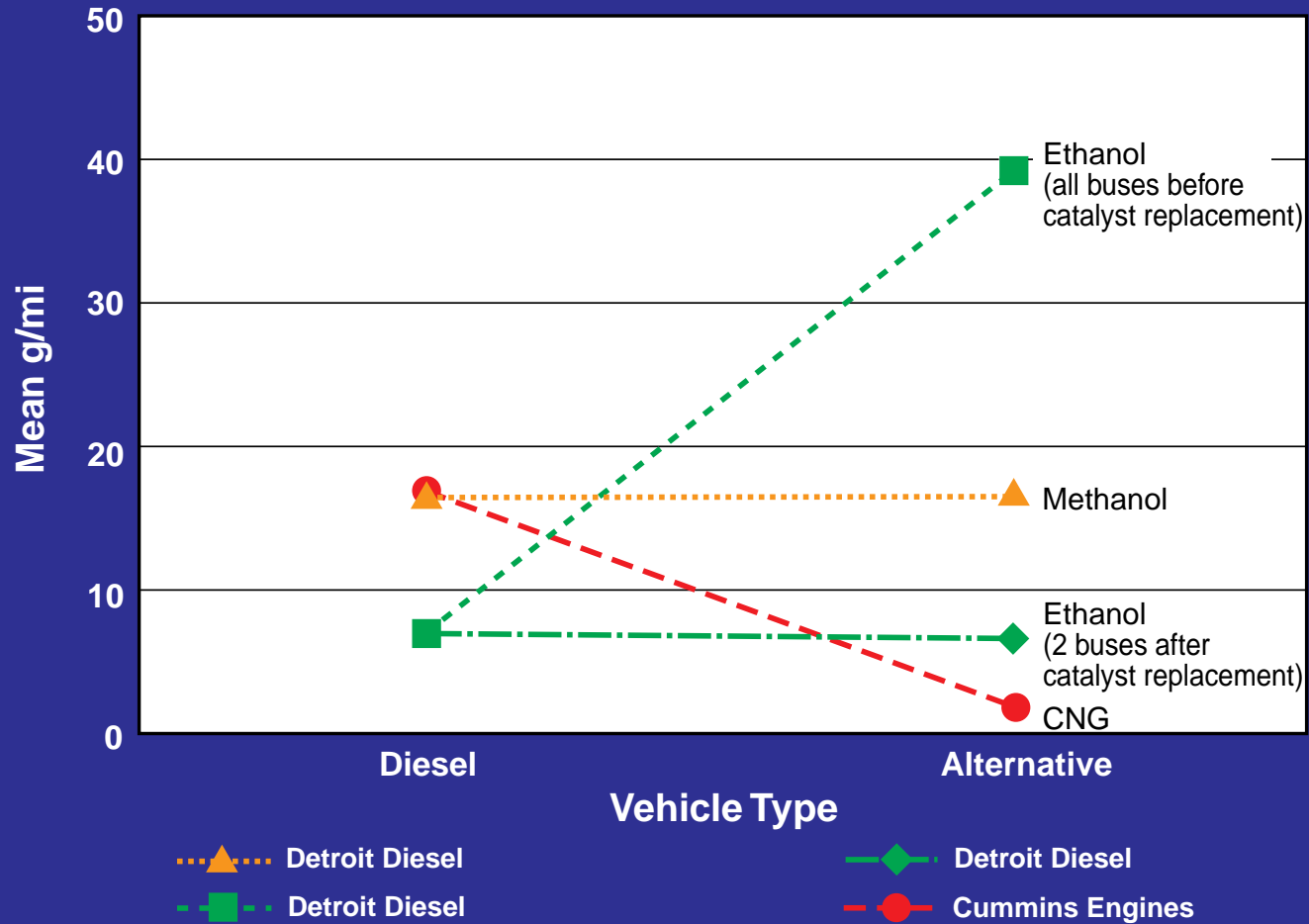


Summary of Test Results for OEM Light-Duty Vehicles (Alternative Fuels Relative to RFG)

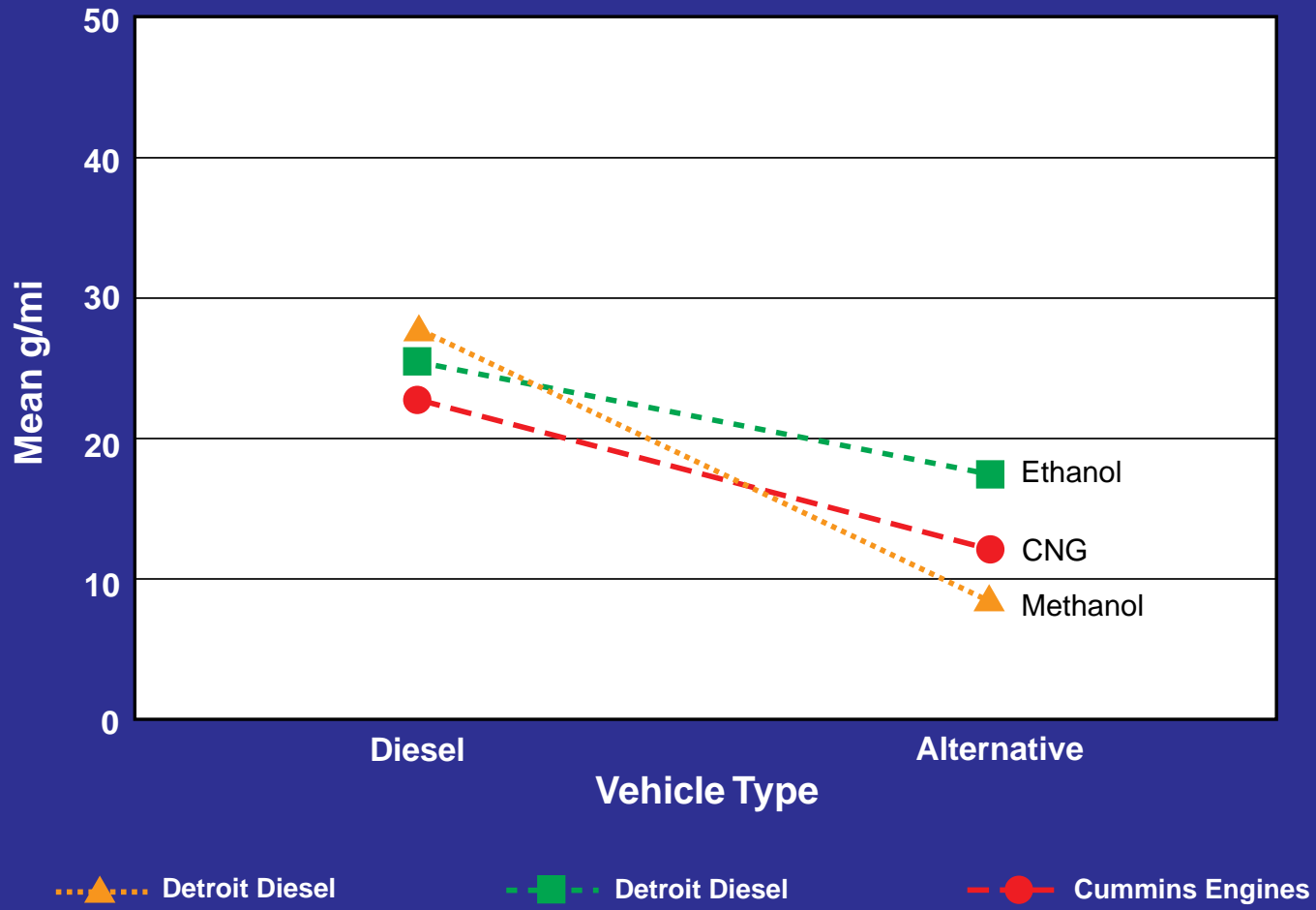
- Regulated constituents
 - Ethanol and CNG
 - CO, HC, NO_x all lower, on average
 - Methanol
 - CO lower, on average
 - HC and NO_x lower or slightly higher, on average, depending on model
 - All below EPA Tier 1 standards
- Toxics and ozone precursors
 - Uniformly lower aromatics, on average (benzene; 1,3-butadiene)
 - Higher or lower aldehydes, on average, depending on the fuel (acetaldehyde; formaldehyde)
 - Lower OFP, on average, for ethanol and CNG
 - Lower or higher OFP, on average, for methanol, depending on model

Round 1 Test Results: Transit Buses

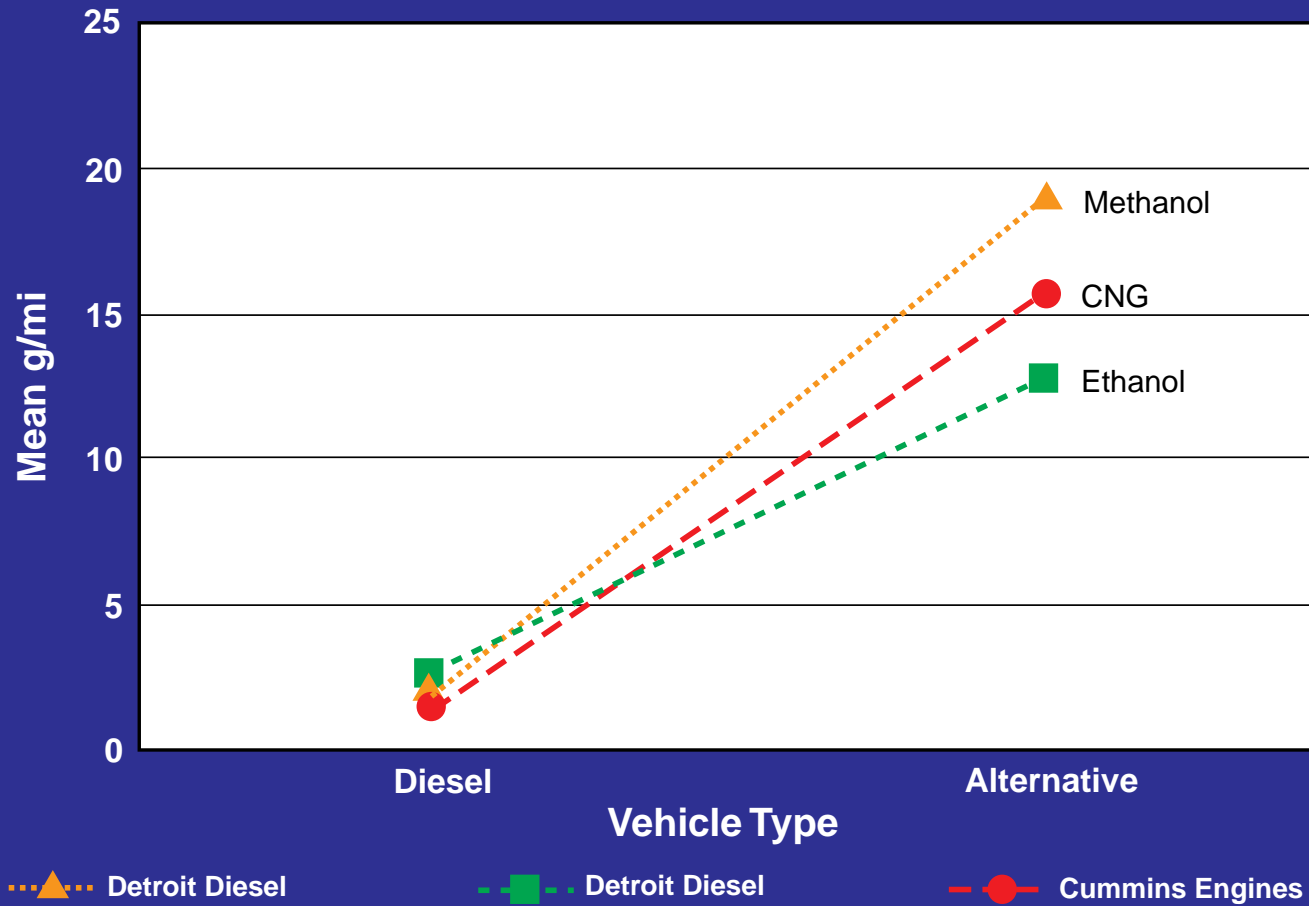
Carbon Monoxide (CO)



Oxides of Nitrogen (NO_x)



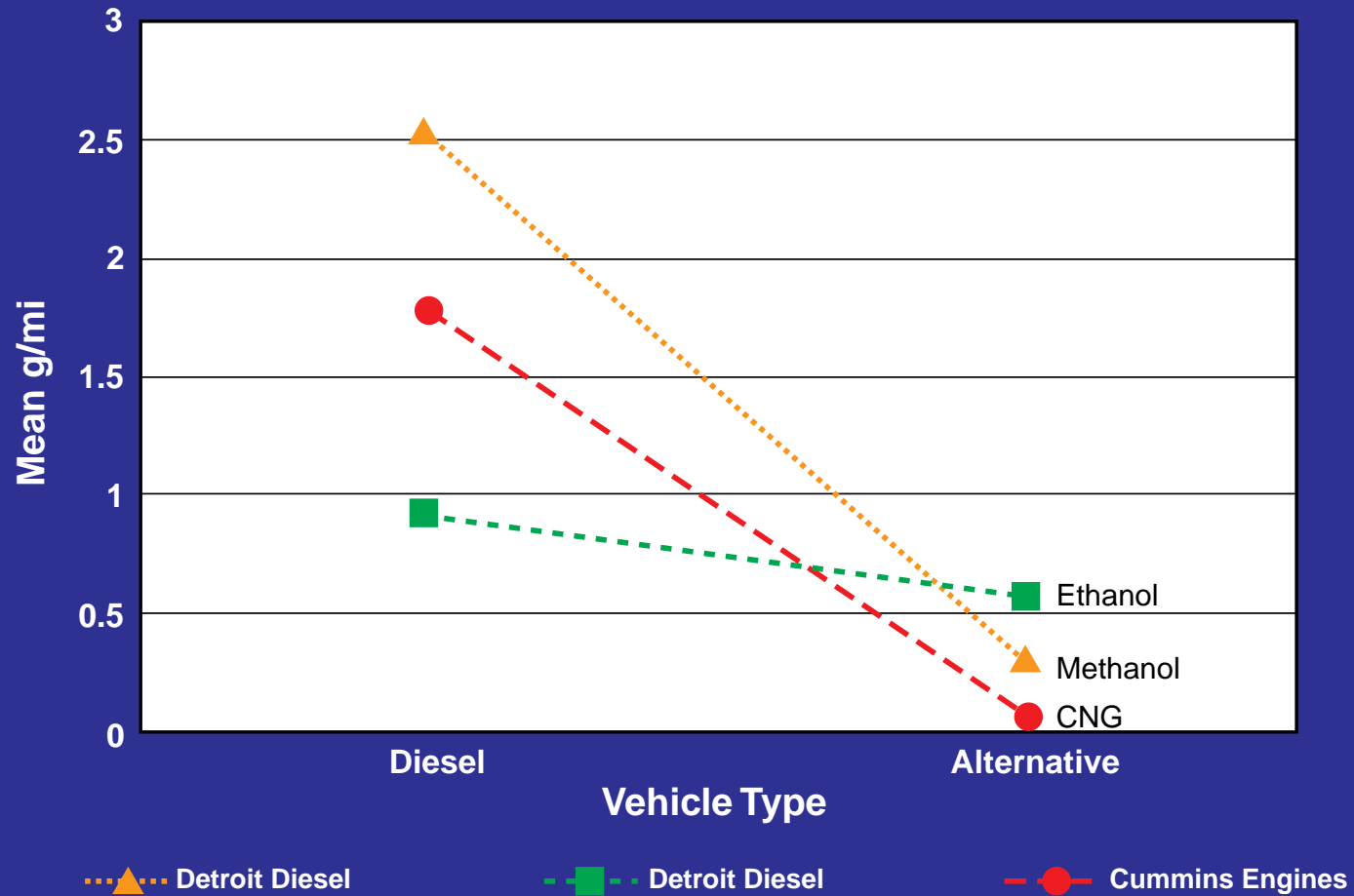
Hydrocarbons*



*Total Hydrocarbons;

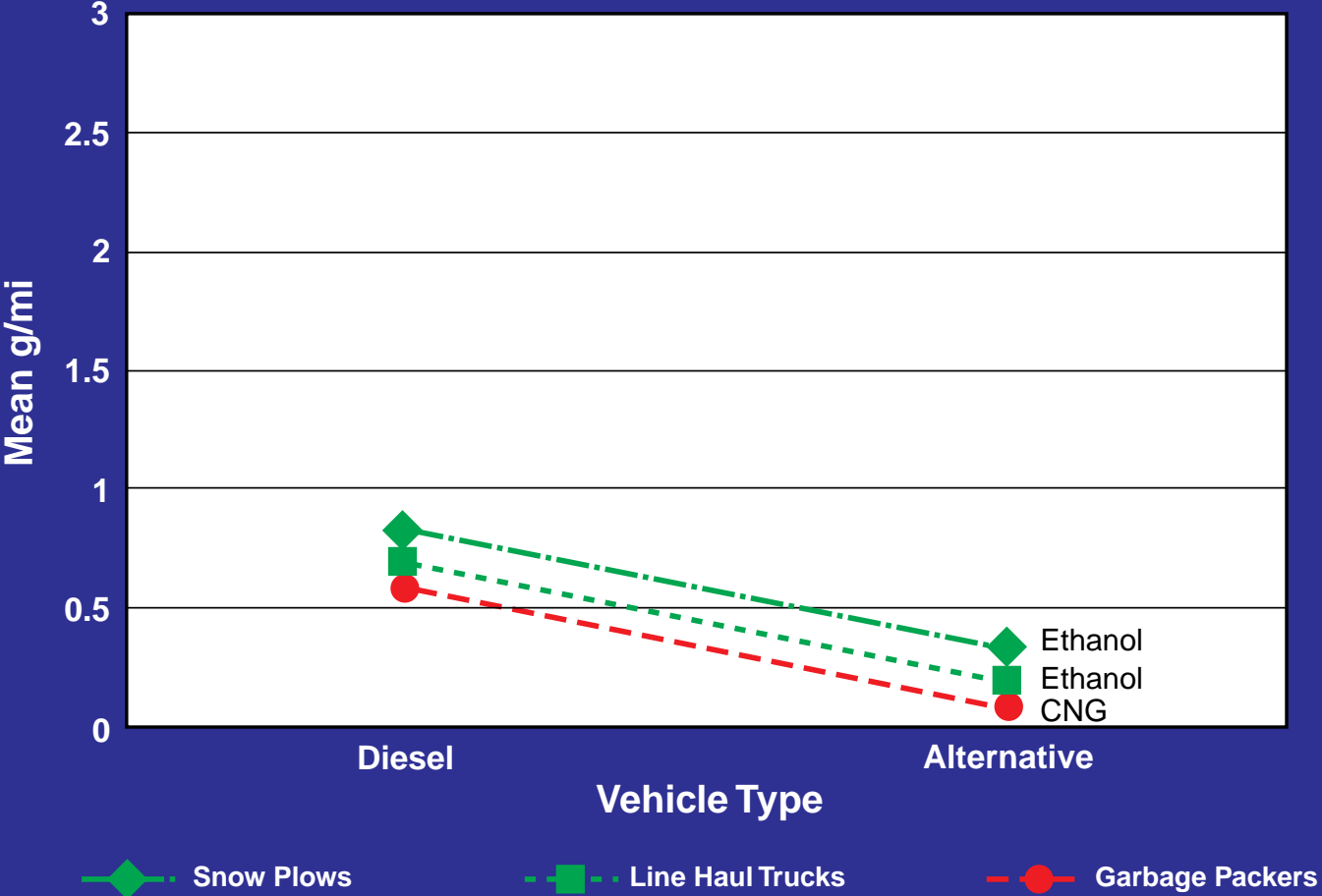
Some engines were equipped with faulty catalysts which adversely affected emissions of hydrocarbons

Particulate Matter (PM): Transit Buses (41 AFVs, 31 Controls)



Round 1 Test Results: Other Heavy-Duty Vehicles

Particulate Matter (PM): Heavy-Duty Trucks (12 AFVS, 5 Controls)



Summary of Test Results for Heavy-Duty Vehicles (Alternative Fuels Relative to Diesel)









































- Transit buses
 - Uniformly lower PM and NO_x, on average
 - Variable results for CO and HC
- Other vehicles
 - Lower PM, on average
 - Variable results of CO, HC, and NO_x

Comments on Heavy-Duty Emissions















- Engine certification data indicate that alternative fuels have the potential to reduce regulated emissions
- Certification standards focus on reducing PM, without affecting NO_x
- In-use emissions testing technology is still developing
- Alternative fuel engine technology is still developing; careful ongoing maintenance and repair is important to emissions performance
- DOE/NREL R&D efforts are continuing

Round 1 Test Results: Light-Duty Aftermarket Conversions














Washington, D.C. CNG Conversion Vehicles — *Kit make: GFI*





Vehicle Model	Model Year	After Conversion (RFG)			After Conversion (CNG)		
		NO _x	CO	NMHC	NO _x	CO	NMHC
Acclaim	1992	NC					
Acclaim	1992	NC		NC			
Astro	1992		NC	NC			
Caravan	1992						
Caravan	1992			NC			
Safari	1993	NC		NC		NC	
Safari	1993	NC					
Taurus	1994		NC				NC
Taurus	1994	NC					NC

Denver CNG Conversion Vehicles — *Kit make: GFI*

Vehicle Model	Model Year	After Conversion (RFG)			After Conversion (CNG)		
		NO _x	CO	NMHC	NO _x	CO	NMHC
B250	1994	NC	NC	NC			
B250	1994		NC	NC			
C1500	1994	NC		NC			
C1500	1994	NC	NC	NC			

Denver LPG Conversion Vehicles — *Kit make and model: IMPCO ADP*

Vehicle Model	Model Year	After Conversion (RFG)			After Conversion (LPG)		
		NO _x	CO	NMHC	NO _x	CO	NMHC
F150 pkup	1994				NC		
F150 pkup	1994	NC			NC		
Taurus	1994	NC		NC			

-  Large emissions increase (>50%)
-  Moderate emissions increase (10%–50%)
-  Moderate emissions decrease (10%–50%)
-  Large emissions decrease (>50%)
- NC = No change (i.e., less than 10%)

Summary of Test Results for Light-Duty Aftermarket Conversions

- Generally higher levels of CO, NO_x, or both for gaseous fuel vs. RFG
- Other considerations
 - Potential positives
 - Ozone forming potential
 - PM and Exhaust toxics
 - Off-cycle emissions
 - Potential negatives
 - Conversion of new, relatively clean (Tier 1) vehicles
 - Use of less-advanced kits
 - Poor, untested installations
 - Deterioration

What Other Reports Say

SAE Paper 952380, *Correcting Emissions Problems in Existing Propane and Natural Gas Vehicles in British Columbia*, Province of British Columbia Ministry of Transportation and Highways, October 1995.

Conclusions of Phase One:

“Emissions performance of propane and natural gas converted vehicles is still inferior to OEM gasoline performance, even when feedback control systems are employed...”

What Other Reports Say

An Evaluation of the City of New York's Alternative Fuel Vehicle Program for Fiscal Year 1995, New York City Alternative Fuel Vehicle Task Force, September 1995.

Conclusion:

“The Chrysler Vans...demonstrated outstanding emissions performance....the magnitude by which the sample exhibited decreased emissions was impressive.

On the other hand, the task force has a similar high degree of confidence that the converted Taurus sedans will increase emissions of NO_x over their gasoline counterparts....It is of great concern to the task force that there is a NO_x increase and that the magnitude of the increase was nearly as high as the amount of NMOG reduced.”

Summary—Findings to Date

- AFVs have generally improved emissions profiles relative to conventionally fueled vehicles
 - Regulated exhaust
 - Toxics
 - Particulate matter
 - Ozone forming potential
- Reductions are most wide-ranging for light-duty vehicles, but heavy-duty vehicles are showing great promise
- Conversions show worse performance than expected
- Study results corroborate those from other investigations, but this data set is far more extensive

Recent NREL Publications

- “FTP Emissions Test Results from Flexible-Fuel Methanol Dodge Spirits and Ford Econoline Vans,” SAE 961090, 1996
- “Round 1 Emissions Test Results from Compressed Natural Gas Vans and Gasoline Controls Operating in the U.S. Federal Fleet,” SAE 961091, 1996
- “Federal Test Procedure Emissions Test Results from Ethanol Variable-Fuel Vehicle Chevrolet Lumina,” SAE 961092, 1996



Compressed Natural Gas and Liquefied Petroleum Gas Conversions: The National Renewable Energy Laboratory's Experience

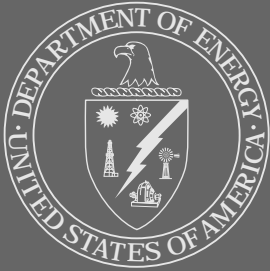


Alternative Fuel Light-Duty Vehicles

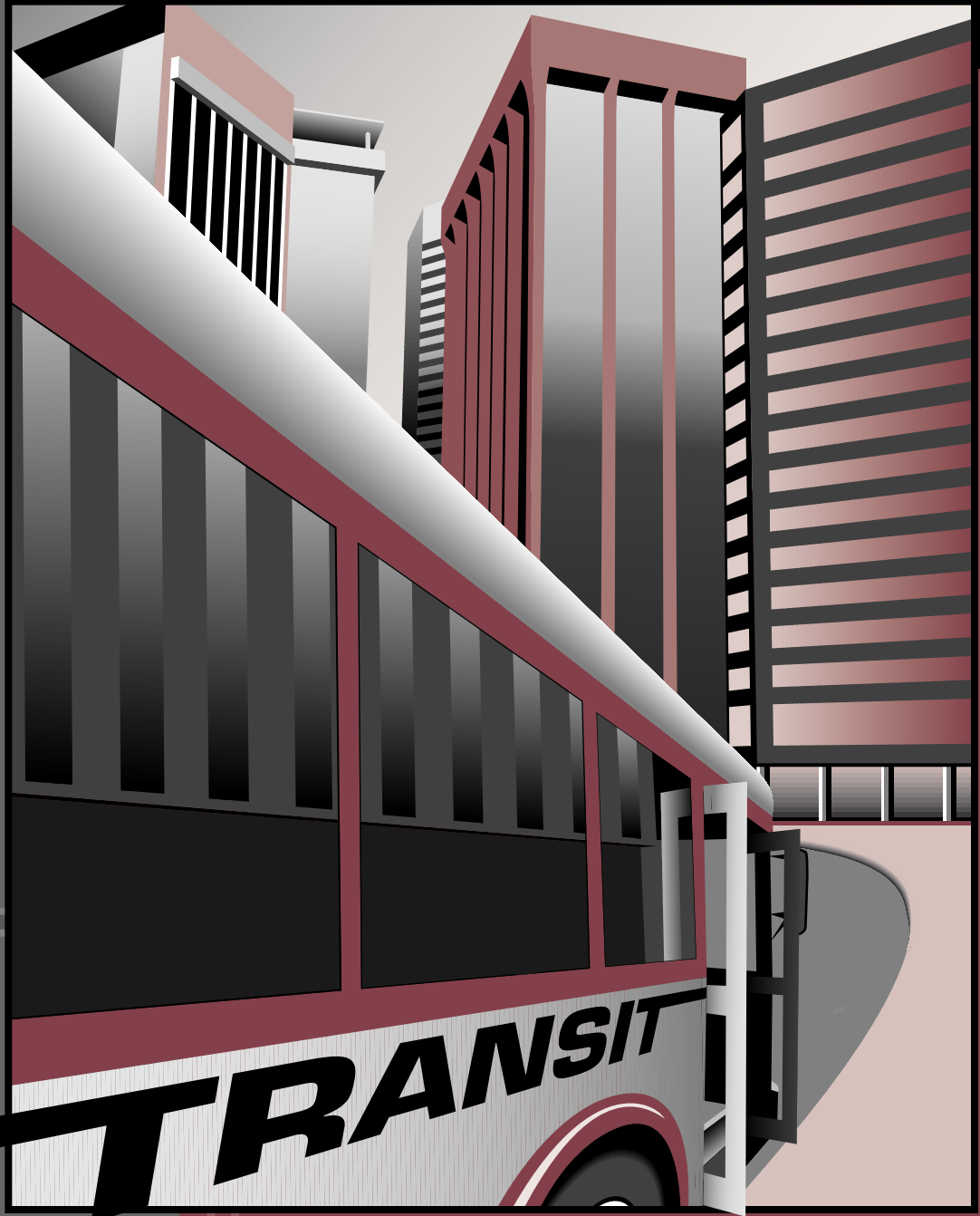


SUMMARY OF RESULTS FROM THE
NATIONAL RENEWABLE ENERGY LABORATORY'S
VEHICLE EVALUATION DATA COLLECTION EFFORTS

Alternative Fuel Transit Buses



Produced for the
U.S. Department of Energy (DOE)
by the National Renewable
Energy Laboratory (NREL),
a U.S. DOE national laboratory



**Final Results from the
National Renewable Energy Laboratory
Vehicle Evaluation Program**